Proc. 12th New Zealand Geothermal Workshop 1990

IN-SITU RESISTIVITY MEASUREMENT OF VEINS IN EPITHERMAL GOLDMINES NEAR WAIHI

Chris J. Bromley Robert H. Funnell

DSIR Geology 81 Geophysics, Wairakei, Private Bag, Taupo

ABSTRACT

Detailed DC resistivity measurements using a variety of electrode arrays have recently been conducted across known epithemal vein deposits near Waihi (namely Golden Cross Mine, and Martha Hill Pit), in order to improve our understanding of the geophysical signatures associated with these types of ore bodies.

The measured resistivity values vary widely from more than 2000 ohm-m within massive quartz veins to less than 30 ohm-m in flanking pods of intense clay alteration. A vector gradient-array traverse across the Martha Pit shows a good correlation between resistive structures and gold-enriched veins. Strong deflections in the azimuth of the electric field are associated with obliquely intersected veins. At the Golden Cross Mine, dipole-dipole data show anomalously strong induced polarisation responses and the gradient array data show a very strong deflection in the azimuth of the electric field.

Further interpretation of these observations, together with 2-D modelling and rock property measurements, is expected to assist future planning and interpretation of geophysical borehole logging and surface-based exploration surveys of similar epithermal prospects.

INTRODUCTION

Resistivity surveys are frequently used to explore for fossil epithermal mineral deposits as well as their high temperature equivalents, active geothermal systems (Allis, 1990). Reduced resistivities are expected where hydrothermal alteration or weathering has produced concentrations of clays (such as smectites, kaolinite, chlorite, illite, etc), whereas increased resistivities are expected where quartz-veining, calcification and silicification are predominant. Precious metal mineralisation is frequently found to be associated with the quartz-veins and silicification, so the more resistive structures, especially those that are mantled by low resistivity clays, are usually targeted.

The exposure, during mining operations, of *ore* grade veins at two epithermal mineral deposits near Waihi, in the southern Coromandel Ranges of New Zealand, presents an excellent opportunity to test this strategy, and to measure, in-situ, the detailed geophysical signature of such veins. This paper describes the results of closely-spaced resistivity measurements conducted using a variety of electrode arrays across exposed veins at the Martha Hill Pit (an open-cast mine), and an underground exposure of the massive Empire Vein in the Golden Cross Mine. This work is part of a broader research objective to characterise the geophysical signatures of epithermal deposits and study their relationships to the original geothermal systems from which they formed.

MARTHA HILL

At the time of this work (April 1990), the Martha Hill pit was excavated down to a level of 112.5 m asl (1112.5 RL). One of the traverse lines regularly used by Waihi Gold Mining Company for channel sampling was selected for gradient array resistivity measurements at 1 or 2m intervals. This traverse line, labelled 1417.5E and oriented at 340°, is located near the south-westem end of the pit. It transects the original Martha Vein (mostly stope-filled), the Bell Vein (2.5m wide), the Welcome Vein (1m wide) and numerous smaller veins, which fill steeply dipping extensional fractures. Gold and silver generally occurs as electrum in sulphide-rich crustiform banded quartz veins, (Brathwaite and McKay, 1989). In close proximity to the veins, the andesite host is strongly altered (illite and adularia) pervasively silicified and subsequently oxidised by weathering.

Resistivity Methods

Two survey techniques were employed on traverse line 1417.5E. The first is a vector gradient array where the current electrodes remain fixed at a wide spacing (at 1343mN and 1558mN) to straddle the area of interest. Current is passed approximately perpendicular to the veins and a pair of orthogonal potential dipoles is traversed at 1m or 2m intervals across the central region between the current electrodes to detect lateral resistivity contrasts and electric field directions. On a much larger scale, this technique has been successfully used by DSIR to accurately locate the boundaries of active geothermal fields and has since been applied to exploration of several New Zealand epithermal mineral prospects.

Information on changes in electric field orientation can prove useful far identifying resistivity interfaces and vein azimuths. By using an asymmetric square-wave current output, which encodes polarity, it is possible to uniquely determine the direction of electric field deflections. Switching periods of about 20 seconds are used, and any strong IP (induced polarisation) effects are also noted.

The total field apparent resistivity is calculated using the standard formula (given by Bibby and Risk, 1973), for a bipole-dipole 6 electrode array (i.e. 2 current electrodes and 2 pairs of orthogonal potential electrodes). The azimuth of the elecmc field vector is compared with the direction expected in a uniform isotropic medium, and the difference is the amount that the electric field has been deflected by lateral variations in resistivity. For current flow oblique to a two-dimensional discontinuity, the electric field is deflected in a manner analogous to refraction of light through different media. The relationship between the angle of incidence to a discontinuity and the angle of "refraction" is given by:

$$\tan\theta_2/\tan\theta_1 - \rho_1/\rho_2$$

where θ is the angle between the elecmc field direction and the normal to the boundary, and ρ is the resistivity. The maximum theoretical angle deflection (θ_2 - θ_1) approaches 90° for a strongly conducting structure oriented almost perpendicular to the current flow. A narrow resistive structure almost in line with the current also causes a deflection approaching 90°. In a three-dimensional situation it is possible to get very large electric field deflections in response to currents channelling into and out of anomalous conductors, in which case the relationship above does not hold.

The results of the vector gradient array traverse between 1390mN and 1480mN are shown in Figure 1. Gold concentrations from samples taken at the same locations are also presented for comparison. There is a good correlation between resistivity and gold concentration peaks because most of the gold is found in exposed quartz veins which are also resistive. This is confirmed by the profile of quartz vein intersections, showing their present dip, as inferred from higher level intersections.

A broad resistivity high centred just to the south of the Bell Vein at 1464mN suggests a substantial resistive structure at deeper levels, consistent with a southward dipping continuation of this vein. The electric field deflection of about -30° (north-west) is consistent with the observed trend of the vein which is intersected obliquely by the traverse line at an angle of about 35° from the normal. This fits the equation above, using a resistivity ratio of 10 for the increased resistivity within the vein. Most of the other veins are almost perpendicular to the traverse line and azimuth deflections are smaller.

Other predictions, based on the resistivity peaks, can be made regarding the likely extent and dip of known quartz veining and the location of new veins below the 1112.5m level. Subsequent mine excavation should provide a good test of these predictions.

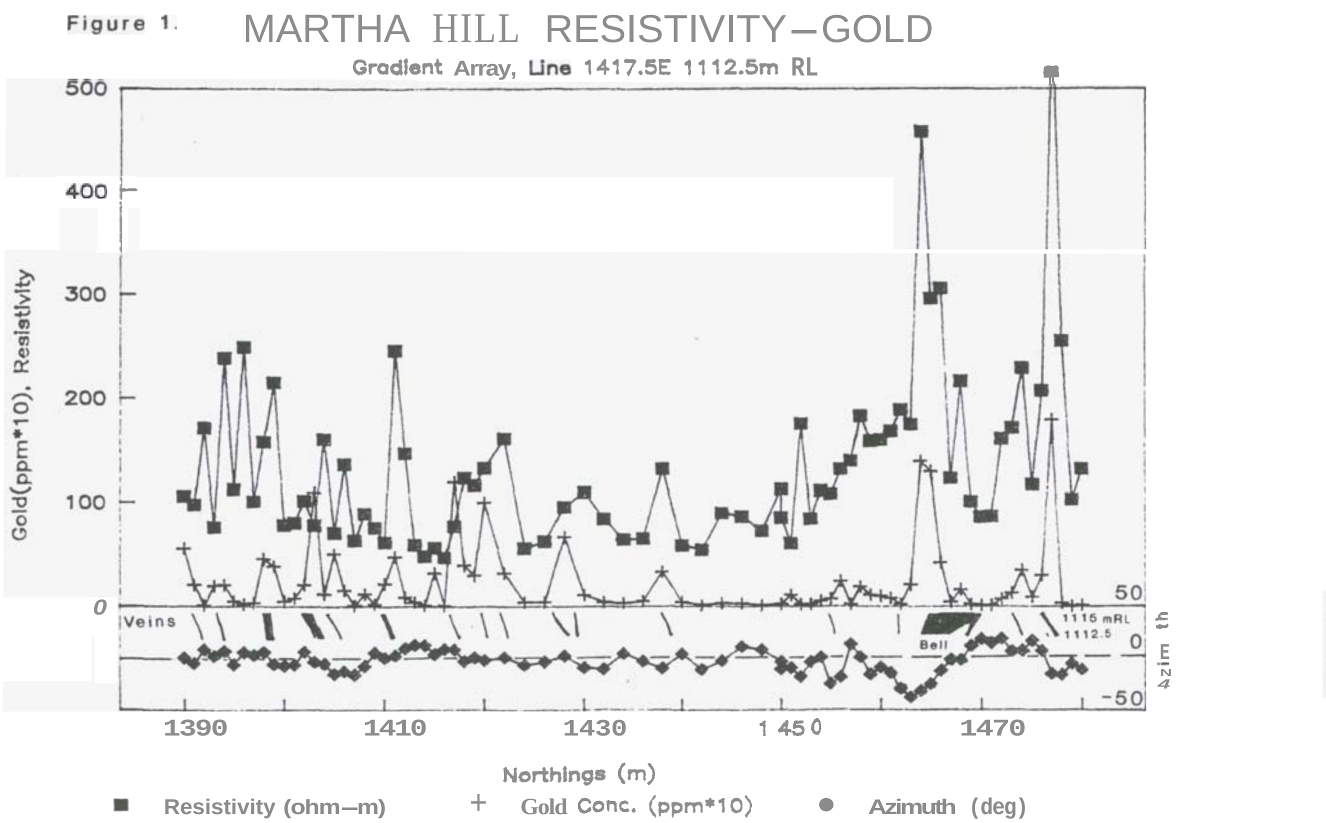
The second resistivity method used along traverse line 1417.5E was a series of over-lapping Schlumberger array soundings with centres spaced about 10m apart, and maximum AB/2 spacings of 50m. In addition, 2 orthogonal soundings were centred on the Bell Vein (at 1466mN). The results, not shown here, generally show a decrease in resistivity with depths below about 10m, which is probably related to the water table. However, heterogeneity causing distortions to the sounding curve at shallow depth invalidate any attempts at simple layered interpretations. The shallow resistivities vary between about 200 ohm-m and 1200 ohm-m (along the axis of the Bell Vein), while deeper resistivities trend towards values consistent with the deeper penetrating gradient array data (about 100 ohm-m). Two-dimensional modelling of veins should be possible using a combination of the sounding and gradient data.

It is concluded from these results that detailed gradient array traverses with dipole spacings of 1m or even less, can resolve narrow quartz veins, and may prove a valuable predictive tool for sub-surface mapping and detection of buried veins when selectively mining an open-cast epithermal gold mine.

GOLDEN CROSS

The Golden Cross deposit is located approximately 8 km north-west of Waihi in the Waitekauri Valley, and is being developed by Cyprus Gold New Zealand Limited. It comprises a deep feeder zone (the Empire Vein) linking to a near-surface stockwork which is surrounded by argillic alteration and partly overlain by unaltered younger andesite (Hay *1989)*. The Empire Vein extends from about 100m to 400m depth, is significantly mineralised along 500m of strike length, and is enveloped by a broader zone (50m) of strong silicification. In a discussion of the history of geophysical exploration at Golden Cross, Collins (1989) concludes that none of the geophysical tools (which included airborne magnetics, gravity, ground magnetics, IP, gradient array, dipoledipole, and CSAMT resistivity) was successful in identifying a clear signature for the main ore zone, the Empire Vein. Although selection of the area was originally aided by the aemmagnetics, and shallow gradient array resistivity did successfully map the near-surface stock-work deposit, the overlying younger andesites appear to have effectively masked the main vein located about 200m further east, and 100m deep. Searching for a solution to this problem is a challenging geophysical research objective.

Figure 1.



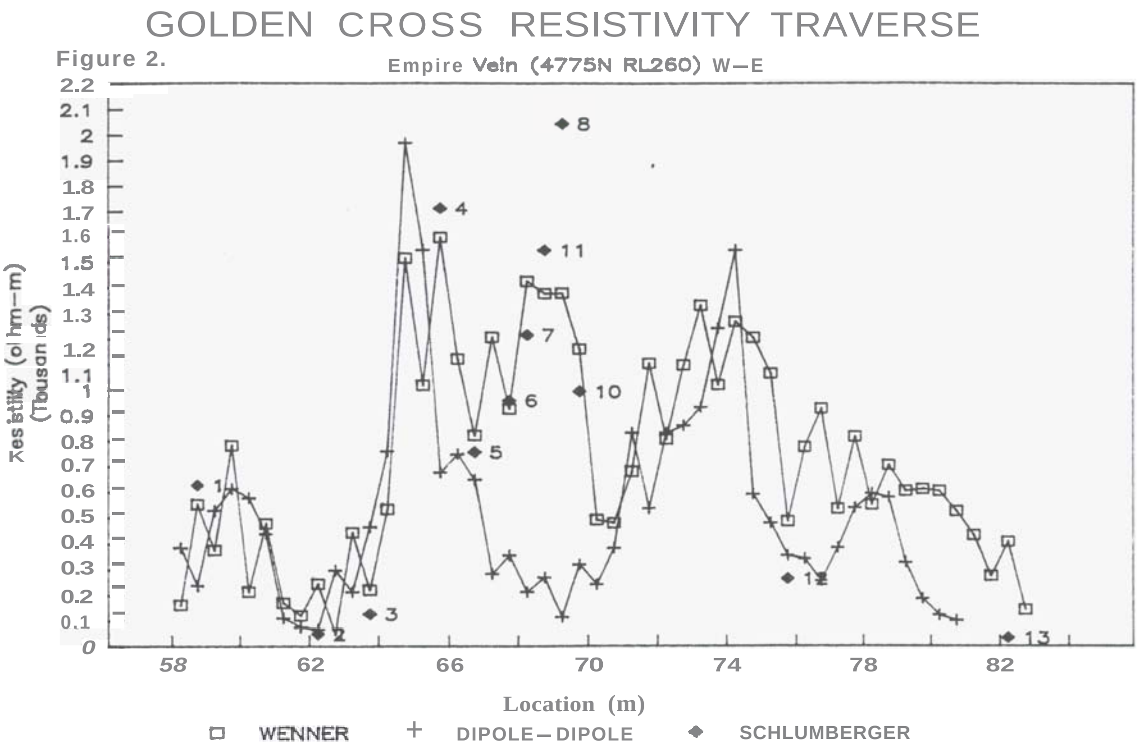


Figure 2.

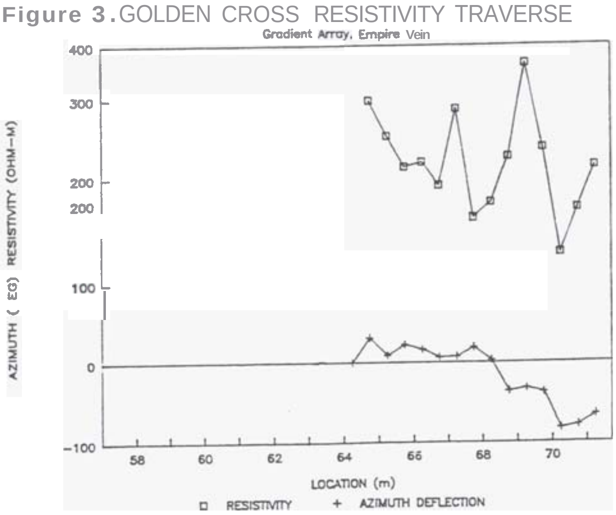


Figure 3. GOLDEN CROSS RESISTIVITY TRAVERSE

As an initial step, it was decided to take advantage of the recent construction of an underground decline and access tunnelling into the Empire Vein at a level of 260m asl (about 170m depth). This tunnelling exposed vein intersections suitable for detailed resistivity measurements and sampling. Precious metals axe largely confined to the *silicified* zone near this level, with higher concentrations coinciding with a zone of inferred subsurface boiling (de Ronde, 1986). The centre of the quartz vein is banded, with milky white quartz interlayered with black siliceous bands containing minor amounts of adularia and pyrite. A 26m traverse across the vein was marked out at 0.5m intervals along the south wall of the cross drive at 4775mN, between 57.5mE and 83.5mE.

Resistivity Methods

Four separate resistivity arrays were tested along this traverse. Measurements using a Wenner array, with current electrode spacing of 1.5m (potential spacing 0.5m), were made at 0.5m intervals. Concurrently, a dipole-dipole traverse (n = 1 only) was recorded using the same 1.5m current dipole, and a 1.5m potential dipole centred 3m further along.

Thirdly, measurements were made across the central portion of the vein (64.75mE to 71.25mE) using a vector gradient array, with fixed current electrodes at each end of the traverse (25m spacing), and orthogonal potential electrodes (0.5m).

Finally, a series of spot Schlumberger array measurements were made using current electrode spacings of 1m and potential spacings of 0.15m. These were located and oriented to provide the most representative in-situ resistivities of the various alteration products and lithologies.

The results of most of these measurements are presented in Figures 2 and 3. They show a reasonable correlation between Wenner array and Schlumberger array data (labelled 1 to 13 on Figure 2) indicating a large resistivity contrast across the vein. Relatively fresh andesite (label 1) has a resistivity of about 600 ohm-m. This drops to values of 20 to 50 ohm-m within the intensely altered flanks of the vein (2 and 13), and increases to values between 500 and 2000 ohm-m within the vein itself (4 to 10). The milky white quark has the highest resistivities (2000 ohm-m) while the black siliceous bands have values of about 1000 ohm-m. There is a pronounced resistivity low within the vein (location 70.5m) which appears to be a narrow zone of crushed grey quartz, and probably contains appreciable clays. This feature also appears as a low resistivity anomaly in the gradient array traverse, along with a dramatic azimuth deflection of about 80°. Such a deflection could be caused by a near-vertical narrow conductive structure.

Data from the dipole-dipole traverse provide some interesting comparisons. Values are plotted beneath the centre of the current dipole rather than midway between the dipoles as in the traditional pseudo-section plot. This produces a closer fit at the beginning of the traverse because the low resistivity under the current dipole dominates the measured resistivity. (For this reason current dipoles are always located in high resistivity ground during roving bipole-dipole mapping surveys of geothermal resources). Elsewhere, the fit between the dipole-dipole data and the other arrays is poor.

It is concluded that the dipole-dipole array is probably inappropriate, in this setting, for traversing large lateral resistivity contrasts. The measured values can be affected by anomalies under either dipole, and are dominated by low resistivities beneath the current dipole. In addition, the dipole-dipole array may be more sensitive to off-line 3-D effects from inhomogeneities.

Another observation concerns strong induced polarisation effects recorded by the dipole-dipole array at stations 61 to 71, and 77 to 81. Values of up to 60% PFE are estimated. These are probably caused by polarising of resistivity interfaces between the quartz and clay, rather than disseminated pyrite. Again, the dipole-dipole array appears to be more sensitive to such effects.

CONCLUSIONS

It has been demonstrated that, on a local scale, mineralised quartz veins within epithermal deposits provide very strong resistivity contrasts. Detection of these contrasts in exploration surveys depends on their width and depth of burial, the background resistivity of the host formation, and the measurement sampling interval. Exploration geophysicists should ideally use methods that provide adequate penetration, but also good lateral resolution of veins that may be only metres in width.

Dramatic azimuth deflections in the electric field have been noted across veins and clay-rich features, which necessitates the use of orthogonal potential arrays. This information may be useful in determining vein or fracture orientations. The dipole-dipole array appears to be more ,sensitive than the other arrays to polarisation effects caused by strong resistivity interfaces, and produces easily misinterpreted lateral resistivity profiles.

Further modelling of these observations and integration with rock property measurements should assist in their interpretation and application to geophysical borehole logging and surface exploration.

ACKNOWLEDGEMENTS

The authors would like to thank Cyprus Gold NZ Ltd and Waihi Gold Mining Company staff who provided willing assistance and encouragement for this work.

REFERENCES

Allis, R G (1990): Geophysical anomalies over epithermal systems. Journal of Geochemical Exploration, Vol.36, p339-374.

Brathwaite, R L and McKay, D F (1989): Geology and Exploration of the Martha Hill Gold-Silver Deposit, Waihi. Mineral Deposits of New Zealand. Aus. I.M.M. Editor D Kear.

Bibby, H M and Risk, G F (1973): Interpretation of dipole-dipole resistivity surveys using a hemispheroidal model. Geouhvsics, Vol.38, No.4, p7 19-736.

Collins, S (1989): Case History of Geophysical Surveys over the Golden Cross Gold Silver Deposit. Exploration Geouhvsics. Vol 20, No.1/2.

de Ronde, C E J (1986): The Golden Cross Gold-Silver Deposit. Monograph Series on Mineral Deposits No.26.Editor R Henley et al. Gebruder Borntraeger, Berlin.

Hay, K R (1989): Exploration Case History of the Golden Cross Project Waihi, New Zealand. Mineral Deposits of New Zealand. Aus.I.M.M. Editor D Kear.

Figure 4: Empire Vein (Golden Cross), southern wall of cross drive at 4775N, 260m RL. Section of resistivity traverse (0.5m intervals) across the edge of the vein (65mE to 69.5mE) showing locations of Schlumberger resistivity measurements 4 to 7.